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Developing optimal ventilation system for a pasta production workshop using mathematical model

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Abstract. The more real conditions differ from the rated ones, the greater error is observed when calculating the aerodynamics and air temperature for specific premises. The paper considers a technique for estimating the efficiency of ventilation systems at the stage of choosing design solutions using mathematical simulation exemplified by a pasta production workshop in Magnitogorsk. Two air change circuits with central and local air conditioners to remove heat have been estimated. Mathematical models were built with the boundary conditions preset, which allowed visually estimating the airflow temperature and velocity field distribution for the circuits studied. Based on the simulation results, conclusions have been drawn on the efficiency of the circuits proposed.

1. Introduction

Modern food industry technologies often involve process designs that do not suppose permanent workplaces in the workshop but require maintaining strict air parameters to ensure proper running of the production process and normal functioning of the equipment. One of such processes is a short pasta production workshop in Magnitogorsk. The pasta production process is performed in the re-equipped bakery building [1], where two closed-circuit automatic lines “Tekalit” and “Buchler” are installed with a capacity of 2 and 4 t/h, respectively. Each line includes a press, a centrifuge, a mixing bath, a shaping extruder, and a trabatto (oscillating pre-dryer), after which an elevator lifts the pasta to the final dryer. Products are thrown onto an oscillating sieve, where they are evenly distributed over the entire dryer width. The process line operation requires maintaining an acceptable ambient temperature within +25-30 °C, which coincides with the requirements of industry-specific standards [2].

Meeting these requirements for air temperature in this workshop is problematic since the building has been designed for other equipment with a much lower heat release rate [3,4]. Also, the climatic conditions of Magnitogorsk in a warm period significantly differ from the design data in the regulatory documents. Thus, for a warm period in Magnitogorsk, the design temperature relating to the B parameters is 25.9 °C. However, due to the dry, sharp continental climate, prolonged 20-30-day heat periods with ambient temperature exceeding 30 °C are often observed in the region. Due to these



conditions, the existing workshop ventilation systems designed for the previous conditions cannot ensure the required process parameters in the warm season, which causes frequent equipment failures and deterioration of product quality.

Thus, when re-equipping the workshop, ventilation systems should be fundamentally reconstructed. To choose the optimal ventilation system reconstruction scheme, the Customer has paid special attention to meeting the regulatory requirements of clause 5.17 [3], i.e. “ensuring the preset microclimate parameters in residential, public, administrative, and industrial premises and buildings for the design working conditions in the cold and warm seasons should be confirmed by calculations or mathematical simulation techniques.” To meet this requirement, air processes occurring in the workshop have been studied for two air change circuit arrangement options [5].

2. The study description

2.1. The study object description

The workshop building has plan dimensions of 54x18x9.6 m. The workshop walls consist of 80 mm thick three-layer metal sandwich panels with mineral wool insulation; the roof is made of 100 mm thick three-layer metal sandwich panels with mineral wool insulation. A large area of the southern facade has been glazed. As glazing, a single glass unit coated with a reflective film has been used. Since a warm period is the most unfavorable to maintain the preset temperature, all air change circuit models have been built for this period. The workshop is heated by solar radiation $Q_{window} = 18,682$ W through the windows and heat $Q_{pr1} = 105$ kW and $Q_{pr2} = 25$ kW released by the first and second process lines, respectively. Thus, in a warm period, excess heat in the amount of $Q_{exc} = 148.68$ kW should be removed.

To create the conditions required, effective air distribution and exhaust system should be developed. The air distribution system can be called effective if the rated microclimate parameters are ensured throughout the entire workshop, i.e. there are no zones of excessive air motion and unacceptable temperature gradient [6]. The analytical formulas to determine the design air change have been obtained under ideal conditions [7]. The more real conditions differ from the rated ones, the greater error is observed when calculating the aerodynamics and air temperature for specific premises [8]. Thus, to solve the industrial ventilation problem, the use of the mathematical simulation technique for each unique case is relevant [9]. The relevance of this thesis is confirmed by the standards of Clause 5.17 [3].

To date, the mathematical simulation technique is the most accurate and visual research method [10]. For this work, the SolidWorks software package was chosen. Using this package, the temperature and velocity field distribution in the studying workshop sections has been estimated [11].

The model has been built for two possible air change circuits applied in the premises. For each circuit, the source data, the geometric workshop model, and the simulation results for a warm period (temperature and velocity field distribution patterns for three sections) have been represented. A comparative analysis of the results has been performed.

2.2. Description of the Mathematical Simulation Results

2.2.1 The air change arrangement No. 1. This circuit is based on the use only *local* systems. Air conditioning *split systems* are selected to remove excess heat with partial mixing of the outdoor air, since the process lines intake air from the working area for drying. For this case, the unit of 4 high-pressure channel air conditioners (3 operating and 1 standby) of the Kentatsu KSTU560HFAN1/KSUR560HFAN3 split system with a cooling capacity of 56.3 kW each has been considered.

Technological ventilation provides for the extraction of automatic lines from the dryer by local fans, the extraction compensation is carried out by external air supplied by channel air conditioners.

The geometric model of the system is shown in figure 1. The air temperature at the air conditioner output is taken $t_{out} = 17\text{ }^{\circ}\text{C}$. Air conditioners operate with a maximum airflow $L_{cond} = 10,800\text{ m}^3/\text{h}$. The mathematical model of the heat and airflow distribution in the drying zone for this case is represented by 2d temperature distribution graphs for the flows in the characteristic drying sections shown in Figures 1-5.

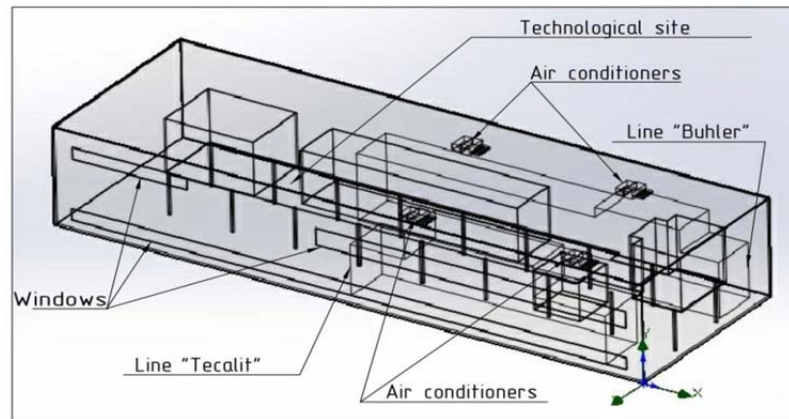


Figure 1. Geometric workshop ventilation model according to scheme No. 1.

Places of cross sections (shown on figure 2) were selected by the location of characteristic equipment: air conditioners and technological fans, that create thermal or speed disturbances.

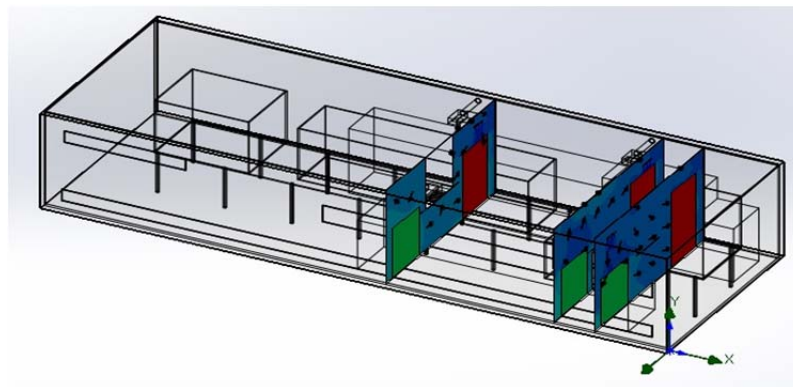


Figure 2. Layout of cross sections.

In figure 3, you can see areas with a lower temperature (the place where the air leaves the air conditioner, an area near the surface of the lines). The air temperature in these zones is $\approx 19\text{--}22\text{ }^{\circ}\text{C}$. There are also areas with high temperature (near the window, on the right side of each line). The air temperature in these zones reaches $\approx 28\text{ }^{\circ}\text{C}$. The average temperature over the cross section is in the range of $\approx 25\text{--}26\text{ }^{\circ}\text{C}$.

In figure 4, you can see areas with a low temperature (the place where the air exits the air conditioner, the area near the surface of the lines). The air temperature in these zones is $\approx 22\text{--}24\text{ }^{\circ}\text{C}$. There are also zones with high temperature (near the window, on the right side of each line). The air temperature in these zones reaches $\approx 28\text{--}29\text{ }^{\circ}\text{C}$. The average air temperature in this section is $\approx 25\text{--}26\text{ }^{\circ}\text{C}$.

In figure 5, you can mark areas with reduced air temperature (only in the supply stream, $\approx 22-24^{\circ}\text{C}$). The average cross-section air temperature reaches values of $\approx 26-27^{\circ}\text{C}$.

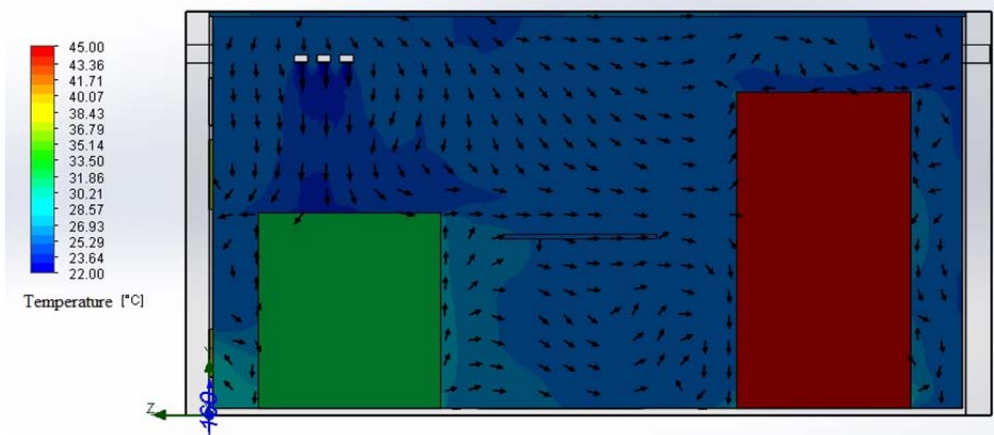


Figure 3. Temperature distribution in section No. 1.

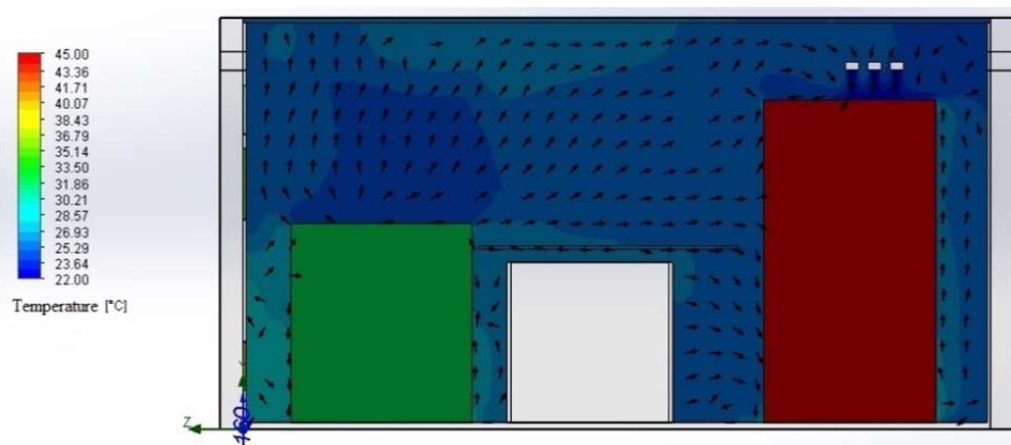


Figure 4. Temperature distribution in section No. 2.

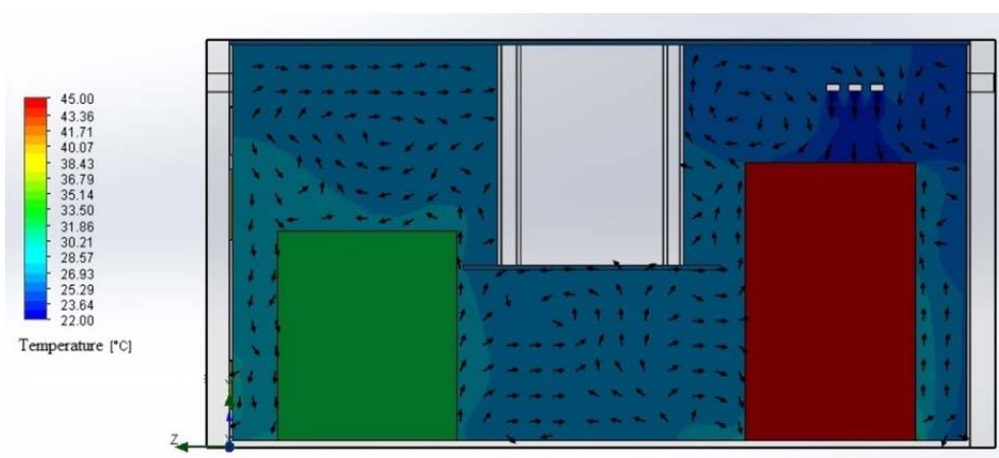


Figure 5. Temperature distribution in section No. 3.

Analysis of the air exchange scheme №1 based on the results obtained:

The scheme allows you to achieve the desired distribution of temperature parameters and the range of outdoor temperatures $t_n=26-32^{\circ}\text{C}$;

With this scheme, small zones may occur:

- with a high temperature (3-4 degrees above the average temperature in the shop) in places adjacent to the window openings (along the entire height of the room), and areas near the side surfaces of technological lines;
- with a reduced temperature (5-6 °C lower than the average temperature in the shop) in the supply stream and on the upper surfaces of process lines
- stagnant areas in the passages between the lines and the outer walls.

However, the influence of these zones does not significantly affect the change in the parameters of the internal air of the workshop.

Due to the location of air conditioners (above the production lines), the speed in the flow is rapidly damped, which has a favorable effect on the microclimate of the production Department.

2.2.2 The air change arrangement No. 2. The scheme № 2, similar to the existing ventilation systems, which involves the use of *central* systems. According to this scheme, in order to assimilate heat surpluses and compensate for technological exhaust, the shop is supplied with supply air with a constant temperature in two installations, through air ducts of uniform distribution. Intake air is supplied after treatment in the air conditioner at $t_{inflow} = 22^{\circ}\text{C}$. To cool the supply air to the design temperature, Central air conditioners are used as installations.

The intake air amount $L_{intake} = 82,550 \text{ m}^3/\text{h}$ is designed for the complete removal of heat. Air is supplied by two air intake units ($L_1 = L_2 = 41,275 \text{ m}^3/\text{h}$) through the uniform distribution ducts of variable section (start section is 1,200x1,200 mm, end section is 500x600 mm) with holes of the same area (300x600 mm).

The shop also provides for General exchange exhaust technological ventilation, which removes air from the shop with roof fans in an amount equal to the emissions from the dryers .

For this case, the mathematical model of the heat and airflow distribution is shown in Figures 6-10
Figure 7 - Layout of characteristic sections to build 2d graphs.

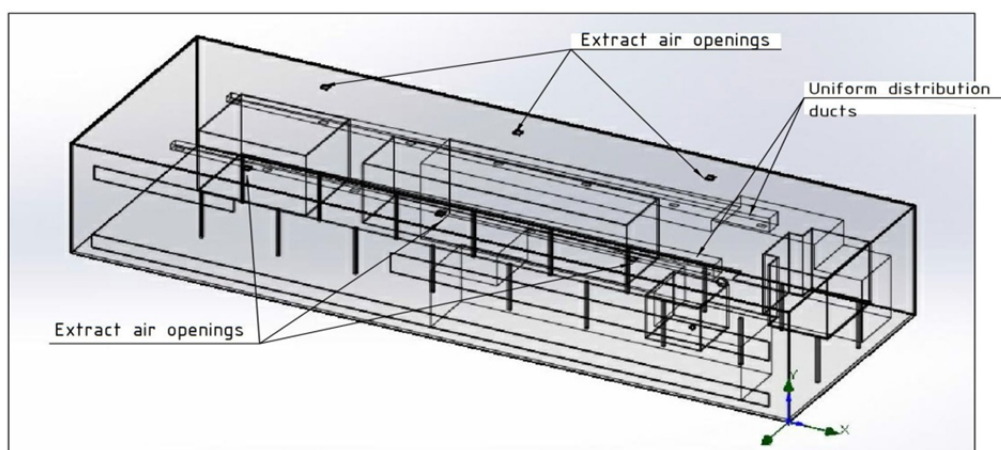


Figure 6. Geometric workshop ventilation model according to scheme No. 2.

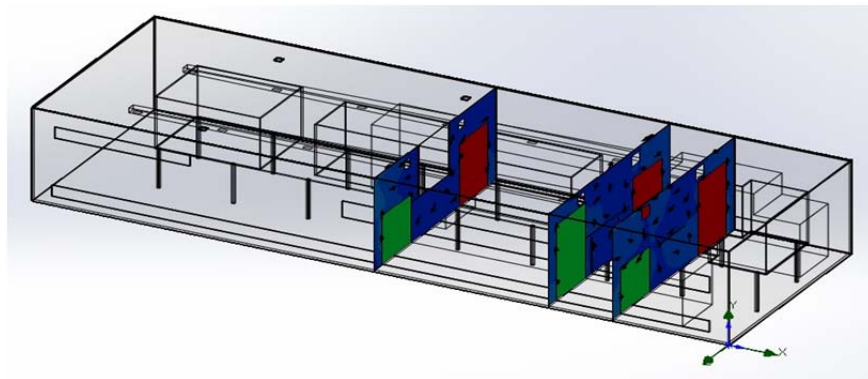


Figure 7. Layout of cross sections.

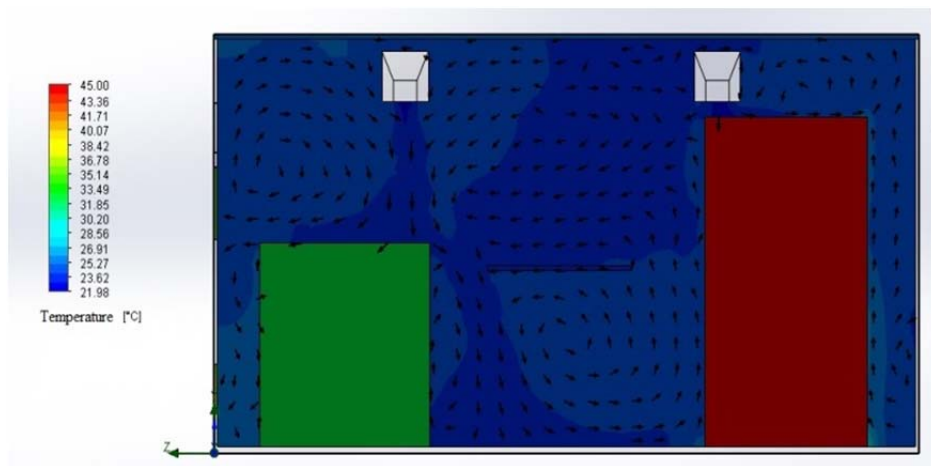


Figure 8. Temperature distribution in section No. 1.

Analyzing figure 8, you can see in section №1 zones with low air temperature (zones in the supply air jets, the zone above the technological platform). The temperature in these zones is $\approx 22-24$ °C. On average, the cross-section air temperature is at the level of $\approx 25-27$ °C.

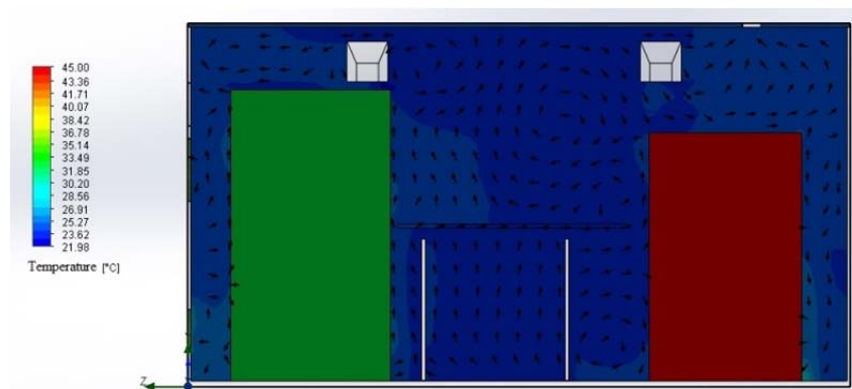


Figure 9. Temperature distribution in section No. 2.

In figure 9, you can see a zone with a low air temperature (the zone between the process lines). The temperature in this zone is $\approx 22-24$ °C. The average cross-section temperature is $\approx 25-26$ °C.

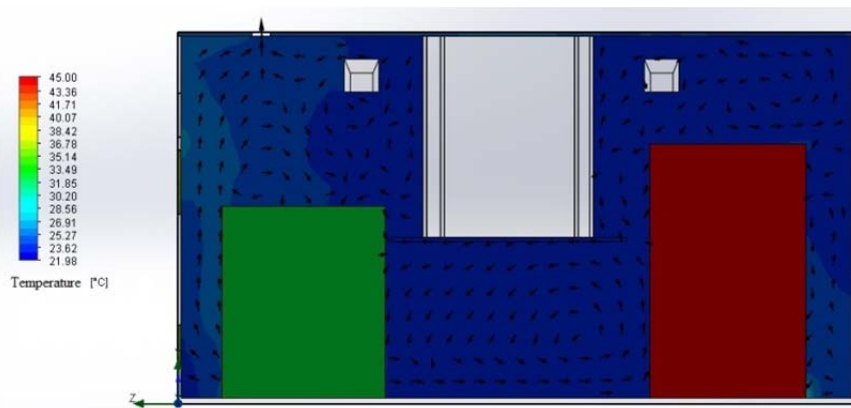


Figure 10. Temperature distribution in section No. 3.

Figure 10 shows an area with a high temperature ($\approx 27\text{--}28\text{ }^{\circ}\text{C}$) near the Windows. On average, the cross-section air temperature is in the range of $\approx 23\text{--}25\text{ }^{\circ}\text{C}$, which is below the required range of internal air temperatures.

Analysis of the air exchange scheme №2 based on the results obtained:

1. Scheme 2 allows you to achieve the desired distribution of temperature parameters in the range of outdoor air temperatures $t_{\text{ext}}=29\text{--}32^{\circ}\text{C}$.
2. With this scheme it is also possible to create small zones:
 - with a high temperature (3-4 degrees above the average temperature in the shop) in places adjacent to the window openings (along the entire height of the room), and areas near the side surfaces of technological lines;
 - with a reduced temperature (3-4 degrees below the average temperature in the shop) in the supply stream and on the upper surfaces of process lines;
 - stagnant areas in the passages between the lines and the outer walls.

However, the influence of these zones does not significantly affect the change in the parameters of the internal air of the shop.

In this scheme, excessive air mobility occurs in some sections ($>0.5\text{ m/s}$), which does not have a very favorable effect on the microclimate of the room.

2.3 Comparative Analysis of Options. The simulation results showed that both schemes are effective. For the final acceptance of one of the schemes for design, an economic calculation of the cost of implementation of each of the schemes was performed

- The total cost of implementing the scheme 1 is: 3 480 000 rubles.
- The total cost of implementing scheme 2 is: 13 135 450 rubles.

This calculation allowed us to make a choice in favor of scheme N1-a scheme using high-pressure split systems of the channel type with winter options. Additional advantages of the local air conditioning scheme are : more flexible regulation of air parameters within a wide range and lower metal consumption due to the absence of extended air ducts.

Thus, this study has shown that *local* air conditioning systems are able to provide a fairly accurate maintenance of the required temperature and air velocity throughout the entire volume of the production shop, with significantly less energy and material resources compared to traditional *central* systems.

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